Art. IX.—*Photographic Charting of the Heavens.*

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The immense help to astronomy promised by photography, was fully recognised in the earliest days of the practical application of the art, and no sooner had Arago explained to the French Academy of Sciences Daguerre's discoveries in August 1839, than Dr. J. W. Draper, of New York, applied them to astronomical purposes, and the following year presented to the New York Lyceum of Natural Sciences, the first astronomical photograph ever taken, in the shape of a Daguerreotype picture of the moon, which was one inch in diameter, and required an exposure of twenty minutes duration. Dr. Draper and others followed up this early experiment, but the low sensitiveness of the plates then in use, and other difficulties, confined the results to the category of somewhat unsatisfactory experiment for several years. We find some sun pictures were obtained in Paris in 1845, and in the same year, pictures of the stars Vega and Castor were secured by Bond of Cambridge, U.S., and of the moon by the same astronomer in 1850. These experiments, although far from satisfactory, indicated great possibilities, supposing improvements in the art took place. Warren de la Rue, in 1851, made the first substantial advance, which was rendered possible by the discovery of the collodion process. From this time onwards, astronomical photography made steady progress, and gave most valuable assistance in the total eclipses since 1854, and on the occasions of the transits of Venus in 1874 and 1882. For the purpose of recording the apparition, development, and duration of sun spots, photography has given invaluable help, and since 1858, pictures of the sun have been obtained every fine day, first in England only, but latterly in many parts of the world, Photographs of the moon, of exquisite delicacy, are now common, and almost a commercial commodity.

Photographs of the planets and stars have hitherto been obtained unsatisfactorily, and with considerable difficulty, on account of their small amount of light compared with the sun or the moon. With the sun the light is so intense, that the difficulty is to obtain an exposure sufficiently short to avoid destroying the sensitive surface, and with the moon even a second or two is enough for telescopes of moderate dimensions. The apparent motion of these bodies in that space of time, is also so small as to require no very special contrivances to compensate for it. With stars and planets, however, where the light is but an insignificant fraction of even that of the moon, the time of exposure has to be so much prolonged, that the earth's diurnal motion renders good photographs quite impossible without the most delicate mechanical means for keeping the telescope pointed precisely and without the least deviation, on the star or planet for many minutes, or even hours. For this reason, although many efforts and experiments have been made in this direction, it is only comparatively recently that the great difficulties presented have been so far overcome as to bring this department of astronomical photography within the realms of practical work. The first important step towards this end, was the invention of the gelatine bromide plate, with its wonderfully sensitive film, reducing many times the period of exposure required for the old collodion plates ; and secondly, the devising of driving clocks for equatorial telescopes, with automatic controlling appliances, so accurately constructed that the telescope follows the motion of a star so precisely, that a plate exposed on a group of stars for an hour, will show each star as a distinct and round black spot, of a size proportional to the star's brightness, instead of a *black line*, which would result if the motion of the telescope did not exactly correspond with the motion of the earth; and fainter stars, quite invisible to the naked eye, either in the sky or on the plate, are seen under the microscope as minute and absolutely round black spots, showing unmistakably the accuracy of the movement of the telescope. These two improvements have made it possible to extend the use of photography to one of the most important branches of astronomy, that of cataloguing and charting the stars.

Immediately after the introduction of the gelatine films in 1883, we tried to get some star photographs with our great telescope, with only partial success, owing chiefly, I believe, to the difficulty of getting the necessary smooth and uniform motion of the telescope. Still, some of the photographs, viewed in the light of our present experience, are of high promise and encourage further experiments. Some prints from these photographs are on the table. These were taken with some of the early gelatine plates made by Edwards in London. A photograph print of the group *Kappa Crucis*, will be found interesting to compare with a print obtained from a photograph of the same object taken with the astrographic telescope.

The first photograph of a nebula taken in the Southern Hemisphere, was obtained with the great Melbourne telescope in February 1883.

Star photography reached the stage of practical success in the hands of the brothers Henry, of Paris, in 1885. The Paris Observatory had been for a long time engaged in preparing elaborate charts of the heavens by the ordinary methods of eye observation, but on coming to the regions covered by the milky way, it became evident that by such a method the work would extend over an impracticably long period; they therefore decided to try the photographic method, and after numerous experiments, both with respect to optical and mechanical means, as well as photographic processes, they constructed a special instrument with which they succeeded beyond their most sanguine expectations. The photographs depicted a great number of stars not visible in a telescope of the same dimensions, and it was soon found that the number of stars impressed on the plate for any particular region, increased almost *ad infinitum* with the time of exposure of the plates. Some very important discoveries of celestial objects at once resulted, many interesting physical facts were revealed, and a new and powerful method of astronomical research established, which opens up an immense range of possibilities.

The Henrys' instrument was a double telescope equatorially mounted, one telescope to be used as a guider, and the other as the photographic camera, both rigidly connected and moving together. The whole was made to follow the diurnal motion of the earth by clock work mechanism in the usual manner, the exception being that this part of the instrument was fitted for more accurate and uniform motion than is ordinarily the case. The photographic object glass was 13·4 inches in diameter, and 13 feet focal length, while the guider telescope had an object glass of less diameter, but about equivalent focal length. This latter telescope is used to keep the instrument pointed always exactly on the same point in the sky, by watching a selected star, which is bisected by the spider web cross in the field of the telescope, and by requisite adjusting motion, kept exactly bisected during the whole time of exposure. A photograph of the Pleiades, obtained by the brothers Henry, exhibited 1421 stars, and a small nebula around one of them, which had never before been seen or suspected. A chart of this group, which had occupied an observer three years and four months, contains 671 stars, so that one hour's photography gave the position of 1421 stars, against 671 in three years and four months by eye observation.

So remarkable a success encouraged the Director of the Paris Observatory, Admiral Mouchez, to address a circular to astronomers all over the world, suggesting that a complete charting of the heavens should be undertaken, as an international work, by the various national observatories. The proposal being favourably received, an invitation was issued to all astronomers to attend a conference on the proposal, to meet in Paris in April 1887. Fifty-eight astronomers attended this congress, Australia being represented by my colleague, Mr. Russell, of Sydney Observatory. The congress agreed to the main propositions and passed a series of resolutions on most of the vital points, leaving the further consideration of details to several selected committees. Several meetings of members of the congress have since been held, the last being in March of the present year, when nearly all the minor points left to the committees were settled, and Admiral Mouchez declared the work of the international astrographic charting of the heavens had now commenced.

The earlier resolutions fixed the dimensions and optical characters of the photographic telescopes, the size and kind of photographic plates, times of exposure, and magnitudes of the stars to be secured on the plates. Subsequent decisions allotted particular portions of the heavens to each participating observatory, numbers of plates to be exposed to each two square degrees of the skies, and so on. Questions concerning the after measurements of plates and final formation of charts and catalogues remain still to be disposed of.

The summation of the work of the congress is briefly as follows :—It was agreed to undertake a photo. chart of the heavens of all stars down to the 14th magnitude, as they will be in the year 1900. Each participating observatory is to provide itself with a twin telescope, equatorially mounted, one for photograph camera, having an aperture of 33 centimetres (13·4 inches), and a focal length of 3·5 centimetres (13 feet), the other of about the same focal length, but of less aperture. The photographic object glasses were to be specially constructed with curves calculated for the wave lengths near the Fraunhofer line G. The exact form and dimensions of the twin guide telescope were left to the several observers participating. Gelatine bromide plates, 6¼ (166 millimetres) square to be used (particular make, left also to observers). These plates cover a little over two degrees square at the equator. Two sets of plates to be exposed, one for the catalogue to secure all stars down to the 11th magnitude, the other for the chart to contain all stars down to the 14th magnitude. Each set of plates to consist of two series, one to cover every successive 4 square degrees, and the other to cover the junction of four contiguous plates in such a way that its four corners correspond with the centres of these four contiguous plates. Eighteen observatories take part in the undertaking—eleven in the Northern, and seven in the Southern Hemisphere. For division of the work among these, the sky is partitioned into zones, and certain zones given to each observatory in such a way that no observatory will have to work very far from the zenith. Melbourne has the greatest range in this respect, as the zones from 65 degrees south to the pole are allotted to our Observatory, which gives us a zenith distance of 52 degrees. This was unavoidable, as Melbourne is the most southern of the very few observatories in the Southern Hemisphere. For every plate in each zone, a guide star has to be previously selected, and it was decided by the congress committee that such guide star must be within 22 min. of arc from the centre of the plate to which it belongs. This guide star is used as already described, and its position has to be exactly determined by transit observation to establish a date point to which all stars in the photograph have to be referred in the final measurements. The determination of these guide stars is in itself a great work, for although the position of a considerable number have already been well determined, and are to be found in existing catalogues, especially in the Northern Hemisphere, there are still a very large number of plates for which guide stars have to be found, and positions determined. To cover the whole of the sky with two sets of plates, will require nearly 42,000 plates; the Melbourne zones will require 2298.

It has been found that the gelatine films of the plates sometimes shrink unequally in drying after development. Such a thing would of course vitiate the subsequent measurements of the stars' positions as shown on the plates. To obviate this, the following plan has been adopted:—A glass plate exactly the same size as the photographic plate, $6\frac{1}{2} \times 6\frac{1}{2}$, is silvered on one side. This silvered surface is ruled into squares by extremely fine lines, five millimetres apart; the lines show as clear glass, and allow light to pass through. Each photographic plate before being used is placed in contact with this ruled plate and exposed for a second or two to parallel rays of light, which, passing through the rulings, impress a latent image on the film, and when developed after exposure to the stars in the telescope, exhibits the stars on a plate traversed by a network of extremely fine lines. If, now these lines are exactly five millimetres apart after the film has dried, it shows that there has been no distortion in shrinkage; if not, the amount of shrinkage can be measured. The silvered and ruled plate is called "the reseau," and every plate, before being used for charting, has to be exposed to the reseau as described.

Having explained the general scheme, I propose now to give a brief description of the arrangements made at our Observatory for the Melbourne portion of the work. The congress left it to the several astronomers to get their telescopes constructed on any plan and by any maker they chose, stipulating only that the photograph telescopes should all be of the same optical character and dimensions, viz., thirty-three centimetres aperture, and thirteen feet focal length, and the object glass to be corrected for the wave length about G. Several instruments were made in Paris, some in Germany, and some in America. Those for British and Australian observatories were made by Sir Howard Grubb, of Dublin, and ours is one of these. It consists of a twin telescope on a massive equatorial stand of the German form, with an unusually long declination axis to allow of plenty of room about the eye end when the telescope is pointed to the meridian. Both the photograph and guider telescopes are made with strong steel tubes connected one with another in a most rigid manner. The photographic telescope is provided with a metallic plate holder, having all necessary adjustments, and with a shutter to cover the object glass, which can be worked easily from the eye end. The guider telescope has an object glass of ten inches opening, and thirteen feet focal length, and is fitted with a micrometer, with long range slides and an electric lamp apparatus for illuminating the spider webs in the eye piece, and for illuminating the various setting circles, scales, &c. Every means for setting, clamping and moving are found within convenient reach of the hands, when the eye is at the guider telescope. The whole of the moving parts, which amount to nearly two tons, are so balanced and counterpoised as to be operated with the greatest ease, and kept in rotation by the clock work with wonderful smoothness and precision. Nearly everything depends on the precision with which the clock moves the telescope, so as to keep the stars apparently stationary in the field of view. For this purpose, Sir H. Grubb has devised a very beautiful arrangement, which, however, is very difficult to describe without models. The mechanism consists first of a powerful clock gear, driven by a heavy weight and controlled by a peculiar kind of governor. This clock work alone drives the telescope, so as to follow diurnal rotation very closely, and will keep a star for an hour together in the field of view of the telescope, but does not control it so accurately as to keep a star bisected on a single spider line in the eye piece of the guider. To secure this, the maker has made a special electric controlling apparatus, which may be thus described:—The driving clock being adjusted to go as accurately as possible, one of the astronomical clocks in the Observatory is made to send a momentary galvanic current every second to an apparatus attached to the driving clock, called the detector. This is a wheel driven by the clock rotating in forty seconds, having three series of contact teeth on its periphery; pressing on these teeth are three springs electrically connected with another apparatus called a "distributor," which consists of three pairs of electro magnets operating a lever capable of moving right or left and making contact with platinum points, or of being held in a central position by the central electro magnet. The action is this:—The driving clock is set going, and the astronomical clock made to send its momentary currents every second through the detector to one or other of its three springs; if through No. 1, the distributor instantaneously moves to the left platinum point; if through No. 3, to the right, and if through No. 2 to the central electro magnet, keeping the lever neutral. Now, if the driving clock moves the telescope accurately, the astronomical clock current arrives at the moment the detector is making contact with the central spring No. 2, and the distributor remains neutral; if, however, the driving clock goes a little too fast, the current passes through No. 1 spring, and the distributor makes contact with the left platinum point, and if it goes too slow, the current passes through No. 3 spring and moves the distributor to the right platinum point. This works so well, that if the telescope moves $\frac{1}{40}$ of a second too fast, or too slow, it is immediately detected, and works the distributor. Now the "distributor" distributes another battery current to a little mechanism called an *accelerator and retarder*, whose offices are respectively to accelerate or retard the driving clock by very small amounts, according to the operation of the distributor, which is *instructed*, if one may use the word, by the detector. By this means the telescope can be kept following the stars so accurately that any one bisected by the micrometer spider web, will remain there for an hour or more together. The accelerator and retarder apparatus is composed of a pair of accurately constructed epicyclical trains, which cannot be described without models or complicated drawings. Besides these regulators, which are automatically worked as described, there is another pair workable by a hand key with two studs, and battery, so that by pressing one stud it operates the retarder and the other the accelerator.

The following will give a fair idea of the actual work of photographic charting:—The particular parts of the zones to be photographed on a night are arranged beforehand, and the guide stars for each plate selected. The dome being opened up and driving clock set going, the observer sets the instrument on the guide star, and as soon as the telescope is found to be steadily following, an assistant brings the plate holder armed with a photographic plate and inserts it into the plate holder frame of the telescope. The time of exposure being previously settled upon, the observer as soon as all goes quite steadily, opens the exposing shutter, keeping his eye constantly on the guide star, which is now bisected at the cross of the spider webs. The time of opening the shutter is noted, and at the expiration of the fixed time of exposure, as shown by an astronomical clock in the observing room, the assistant warns the observer, who instantly closes the shutter. During the whole time, ten, twenty, forty or sixty minutes' exposure, the observer has to rigorously watch the star and spider webs, and check, by means of the accelerator and retarder hand key, any tendency to leave the intersection, and absolutely to keep the intersection bisecting the star during the whole exposure. Any failure in this respect results in the photographic images of the stars being elongated or oval, instead of round, making them difficult for measurement. One plate being thus exposed it is removed, and the instrument set on the next guide star, and so on. All changing of plates has of course to be done in the dark room, and the observing room itself must be kept moderately dark during the exposure. The development of the plates with us is usually done on the following day.

So far as the Melbourne Observatory is concerned, none of the regular charting has been commenced yet, although for four months past we have been busily engaged in necessary preliminary and experimental work. It was not until the end of March that the Central Congress definitely decided many of the principal questions, and the final instructions have not reached us even yet, nor indeed have the Reseaux, &c., and the appliances for their use. Nevertheless, there are so many preliminary difficulties to be surmounted, and so much to learn regarding the effects of varying atmospheric conditions on the photographic process, and especially as regards time of exposure, that there has been no time actually lost yet. The work will occupy several years—five at least, and probably more. Concerning the more purely photographic part of the work, the relation of magnitudes of the stars to the size of their photographic images on the plates, and the effect of fluctuating conditions of the atmosphere, I hope to be able on some future occasion to contribute some interesting facts.